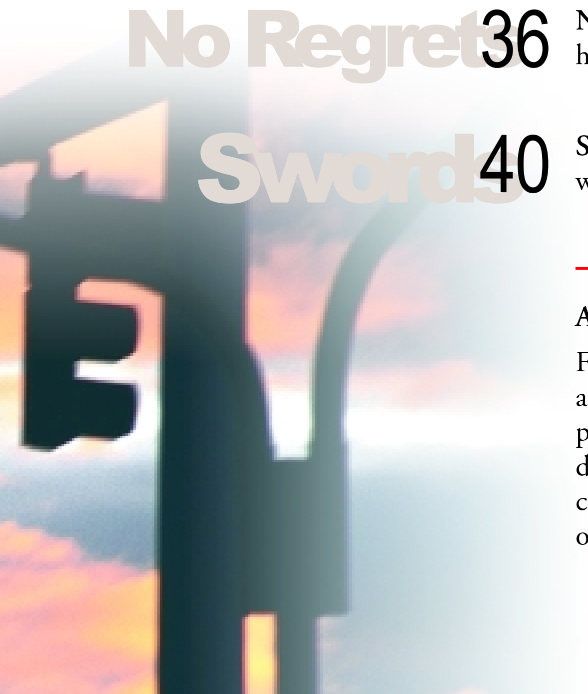
Contents



About the Cover:

Family vehicles in the U.S. consume enough fuel each year to cover a regulation-size football field to a depth of about 40 miles. FETC partners with industry and other organizations to develop and deploy ultra-clean, high-performance fuels, ensuring that we can continue to depend on our transportation-based economy to bolster our transportation-based lifestyle.

John C. Winslow
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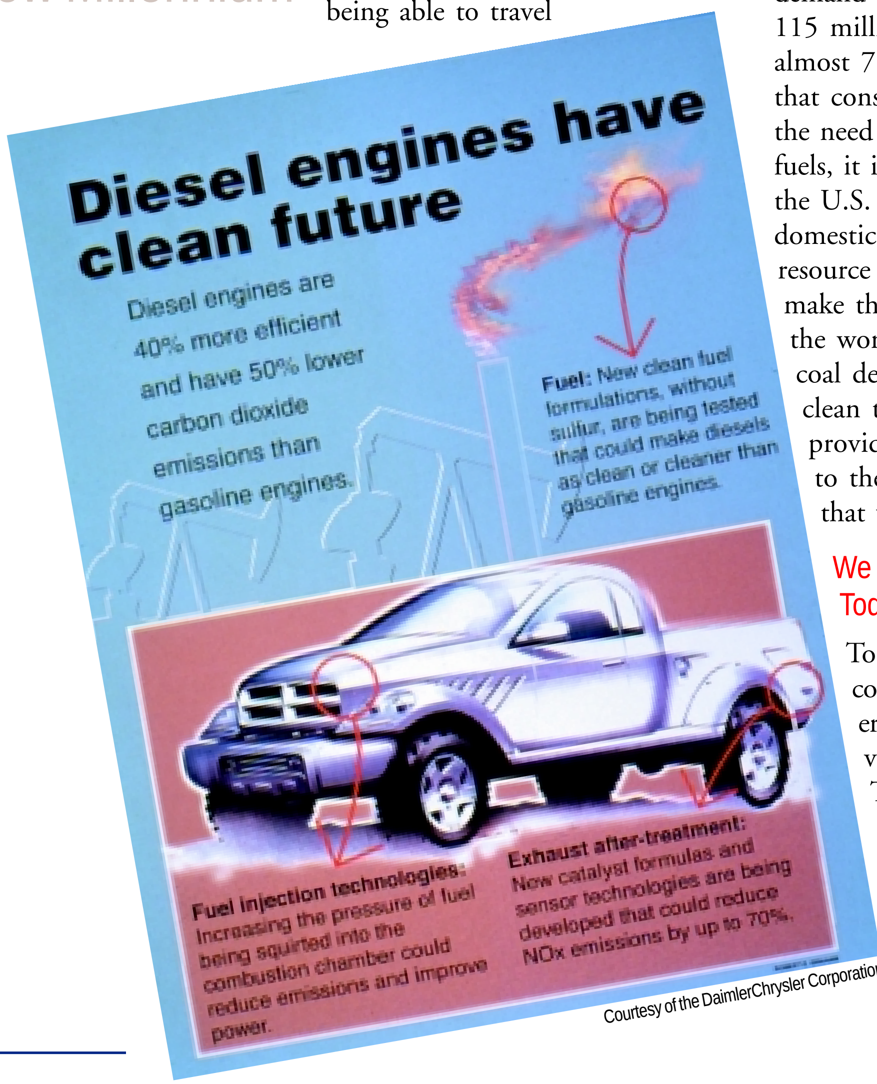
Fuel for the New Millennium

"The horse is here to stay, but the automobile is only a novelty—a fad." President of Michigan Savings Bank advising Horace Rackham (Henry Ford's attorney) not to invest in the Ford Motor company, 1903.

As American as baseball and hot dogs . . . as American as motherhood and apple pie . . . Americans love their cars. To the American teenager, turning 16 is the ultimate achievement—a rite of passage that translates to a driver's license. To the American businessman, driving the right car is a symbol of success. And to the average American, the car is much more than just transportation: it's the freedom to get up and go; it's the convenience of being able to travel at a moment's notice; it's a personal statement of who we are and how we wish to be perceived.

We Americans want it all. We want an affordable, high-performance car that doesn't pollute the environment by spewing smoke, carbon monoxide, and other emissions. However, environmental issues aren't the only considerations for fueling the vehicle fleet of the 21st century. By 2020, world oil demand is projected to be about 115 million barrels per day, almost 75 percent higher than that consumed in 1999. Given the need for more and cleaner fuels, it is in the best interest of the U.S. to expand both the domestic and global fossil resource base from which we can make these fuels. Drawing on the world's huge natural gas and coal deposits to produce ultra-clean transportation fuels will provide significant additions to the petroleum resources that we rely on today.



Courtesy of the DaimlerChrysler Corporation

We Need Tomorrow's Cars Today!

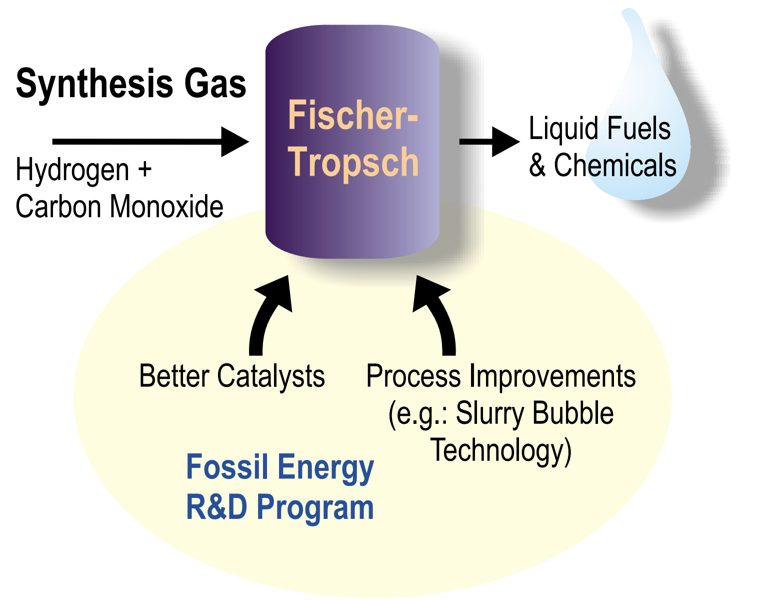
To address environmental concerns, auto manufacturers are developing new vehicle/fuel combinations. The future car will need to be a high-efficiency, low-polluting vehicle that doesn't compromise the comfort and operating characteristics we've come to expect. There are several possibilities for such vehicle/fuel combinations based on recent technological developments. Options include vehicles powered by high-efficiency diesel engines and diesel/battery hybrid vehicles. Recognizing that diesel engines are 40 percent more efficient than gasoline engines and produce less carbon dioxide (CO_2), it's obvious that the next generation of diesel engines could have a significant impact on the automobile industry.

Ultimately, automobile manufacturers envision a fleet of fuel-cell-powered vehicles in which the hydrogen supplied to the fuel cell is manufactured on demand from zero-sulfur liquid fuels carried in a conventional fuel tank on board. These zero-emission vehicles will combine air and hydrogen to produce electricity and emit mainly a water-vapor exhaust. The fuel-cell strategy is already being demonstrated by Ballard in British Columbia and by Daimler-Benz in Germany: their hydrogen-powered fuel cell buses have on-board hydrogen storage. (See "Drink Your Car Exhaust?" on page 30.)

New Cars Mean New Fuels

Ultra-clean vehicles of the future will inevitably require very low-sulfur, perhaps even zero-sulfur, fuels. Vehicle manufacturers have found that sulfur compounds in the engine exhaust can foul the catalytic converter, limiting its capacity to reduce nitrogen oxides (NO_X) and particulate emissions. Consequently, refiners must (1) add more desulfurization capacity at the plant to lower the sulfur content of the fuel, (2) develop technologies to reduce the sulfur content of the crude oil coming into the refinery, or (3) replace some or all of their crude oil purchases with low- or zero-sulfur feedstocks, such as Fischer-Tropsch (F-T) liquids. Other high-value, zero-sulfur alternatives like *methanol* and *dimethyl ether* may require only minimal refining prior to use.

Synthesis Gas Conversion R&D



First used by the Germans in World War II to fuel tanks and heavy trucks, and later by the South Africans during the apartheid era, synthetic fuels are making a comeback. In fact, synthetic diesel fuel, manufactured by the F-T process, was big news at the January 1999 North American International Auto Show in Detroit.

DaimlerChrysler exhibited its concept truck, the Dodge Power Wagon, which features a 7.2 liter Caterpillar diesel engine, and uses F-T diesel fuel. It boasts 40-percent better fuel economy than its gasoline engine counterpart and lower CO_2 emissions because of its high efficiency.

DaimlerChrysler also recognizes that, in addition to refinement of engine and exhaust after-treatment technologies, cleaner fuels will be necessary for widespread consumer acceptance of diesel engines. As a result, DaimlerChrysler is working with Syntroleum of Tulsa, Oklahoma, to demonstrate the potential of Syntroleum's *F-T diesel fuel* (produced from natural gas). Using this high performance, ultra-clean fuel in combination with advanced engines and catalytic converters, could make diesel engines as clean as gasoline engines.

The F-T process was designed originally to convert coal-derived gas to other products. Coal was gasified to form carbon monoxide and hydrogen, which then underwent a reaction to form liquid hydrocarbons. The process resulted in an adequate fuel, given military and political urgencies. However, since its use during World War II, many advances have been made in the technology to reduce costs and improve product quality. Researchers have also shown that the F-T process can be used to efficiently produce zero-sulfur fuel from other hydrocarbon materials, including natural gas, petroleum, petroleum byproducts, biomass, and municipal wastes.

Today's F-T diesel fuel contains 12 percent more energy per gallon than gasoline, and tests of this fuel on conventional, unmodified diesel engines have demonstrated significantly lower levels of particulate emissions and other pollutants than when using conventional petroleum-derived diesel fuel. Even more significant emission reductions are anticipated when F-T diesel fuel is used in advanced diesel engines that have exhaust controls.

The California Air Resources Board is actively promoting technologies that reduce emissions attributable to the transportation sector. The Board is considering F-T diesel fuel as a viable fuel option because of the immediate benefits in reducing NO_X, carbon monoxide, hydrocarbon, and particulate emissions. The much lower emissions provided by F-T fuel use could offer immediate relief to California's growing air pollution problems. Furthermore, reducing particulates is especially important in California, which regulates particulate matter from tailpipes as a toxic air contaminant.

Methanol is a sulfur-free option for meeting stringent vehicle emission standards. Clean-burning methanol can be used in fuel-flexible cars and buses. There is interest among auto manufacturers in converting (reforming) methanol on board a vehicle, and then using the hydrogen that's produced to fuel the fuel-cell-powered vehicle. And using reformed methanol to power a fuel cell means a vehicle with very low emissions.

Another promising new fuel is *dimethyl ether (DME*). This compound, which is manufactured from methanol, is being examined as both a diesel-fuel supplement and as a stand-alone fuel for some diesel engines. Current research on DME is focused on lowering costs through large-scale demonstrations of the single-step conversion of synthesis gas to DME. Automobile manufacturers are interested in DME fuel because the emissions from diesel engines using DME are lower than the very stringent Ultra Low Emissions Vehicle standards set by California.

When Will They Appear At the Pump?

When will these new vehicle/fuel combinations appear at the pump? F-T derived fuels are already being produced commercially at various overseas operations. The SASOL plant in South Africa uses the F-T process to convert coal-derived synthesis gas to fuels and chemicals. Shell's plant in Bintulu, Malaysia, uses the process to convert natural gas to chemicals (mainly wax) and F-T fuel. Domestically, Exxon, Rentech, and Syntroleum have each developed and demonstrated their F-T processes at various scales. Still, technological improvements are needed to facilitate the introduction of ultra-clean fuels at your corner fueling station, including (1) better process efficiency, (2) lower plant and production costs, and (3) lower cost catalysts for converting the synthesis gas to liquid products.

When the market demand for these alternative fuels becomes

Slurry bubble column reactor (SBCR) technology is being tested at the Alternative Fuels Development Unit in LaPorte, Texas. The DOE-owned unit will also be used to demonstrate the conversion of synthesis gas to dimethyl ether (DME).

significant depends on several factors. Technological improvements and cost reductions are part of the story, but the market will probably also be driven by increasingly strict environmental regulations. FETC's strategy to facilitate the introduction of ultra-clean fuels in the U.S. is to address the technology needs through partnerships with industry, academia, and other government organizations.

FETC Research Provides Solutions

FETC researchers are examining ways to reform methanol and other liquid hydrocarbons into hydrogen, since reforming is the most convenient way to get the ultra pure, premium hydrogen needed to power fuel cells.

In the area of F-T technology, FETC is developing slurry bubble column reactors (SBCRs), which convert synthesis gas into high-quality diesel fuel and naphtha, a distillate product that can be further refined to gasoline. Heat transfer is more efficient in an SBCR than in earlier reactors, which makes SBCRs less costly to build and operate. In an SBCR, the catalyst is suspended in a slurry oil and synthesis gas is bubbled through the slurry. Some of the products exit the reactor as vapors, and others are recovered as liquids by removing a portion of the slurry. FETC researchers are involved in this development work. Larger-scale tests are being conducted at the Alternative Fuels Development Unit located at Air Products and Chemicals' facility in LaPorte, Texas.

The LPMeOH™ demonstration project in Kingsport, Tennessee, produces 80,000 gallons of 97-percent pure methanol per day from coal-derived synthesis gas. The demonstration project is the first U.S. commercial use of SBCR technology.

DOE's Liquid-Phase Methanol (LPMeOH™) Clean Coal Technology demonstration project—being performed by Eastman Chemicals in Kingsport, Tennessee—is the result of earlier FETC-sponsored methanol production in LaPorte. This highly successful demonstration project uses an SBCR and, since startup in April 1997, has already produced over 40 million gallons of very high purity (97%+) methanol, all of which has been used by Eastman in its chemical manufacturing facilities.

FETC is researching the use of DME as a diesel fuel supplement, with two objectives: (1) addressing chemical manufacturing issues associated with DME, and (2) testing DME in existing engines. The LaPorte unit will be used to demonstrate a single-step, slurry-phase conversion of synthesis gas to DME. If these results are promising, a commercial demonstration at the Kingsport location is anticipated. In another project, FETC is partnering with the Commonwealth of Pennsylvania, Pennsylvania State University (PSU), Air Products and Chemicals, Inc., and Navistar. DME is being blended with conventional diesel fuel to power a shuttle bus on the PSU campus; the purpose is to reduce exhaust emissions, especially particulates. The PSU demonstration could generate interest in using these types of blends in buses and medium-duty trucks that operate in cities and metropolitan corridors.

Success Through Partnerships: EECPs

Obtaining the vehicle/fuel combinations we need for high-performance, low-emission cars requires coordination between government and industry. And these partnerships must consider more than just fuels. The alternative fuels of the next century and beyond will probably be produced in combination with other products—at facilities that maximize efficiency and minimize waste, the doing-more-with-less way of thinking.

FETC is at the head of the class in designing this new type of facility, called the Early Entrance Coproduction Plant (EECP).

Three companies were recently selected to design EECPs. Each company will lead a project team whose work, during a three-phase

Features of an EECP

- ☑ ***Processes*** multiple feedstocks, one of which is coal
- ☑ ***Produces*** more than one product
- ☑ ***Reduces*** risk such that future coproduction plants may be deployed without government assistance
- ☑ ***Meets*** or ***exceeds*** existing environmental requirements
- ☑ ***Reduces*** CO_2 emissions using mitigation, utilization, or sequestration

development effort, will culminate in the engineering design of a coproduction facility. FETC Associate Director Fred Brown notes: *The projects represent an important first step toward developing advanced technology modules that DOE expects to integrate into "Vision 21," a vehicle for providing high-efficiency, near-zero emissions energy facilities. They will produce electricity along with a slate of other energy products–~~tr~~ansportation fuels, chemicals, and hydrogen—that meet market needs in the next century.* (See "Vision 21: The Ultimate Energy Complex" in the September 1998 issue of *FETC Focus*.)

Waste Management and Processors, Inc. of Frackville, Pennsylvania, will assess the feasibility and economics of a plant that converts coal residue into premium transportation fuels and electricity. Using coal waste not only provides a low-cost feedstock, but also benefits the environment by reclaiming land and preventing a potential pollution problem. The team includes Bechtel National, Inc., a global engineering and construction company; Texaco Global Gas and Power, an integrated energy company with a global presence in coal gasification; and SASOL Technology Ltd., a leader in F-T technology. If the concept is feasible, the team will develop an engineering design package for a plant to be built in Gilberton, Pennsylvania.

Dynegy Power Corporation of Houston, Texas, will evaluate producing power and chemicals from a plant fueled with coal and chemical sludge. Team members are Air Products & Chemicals, Inc., developer of the novel LPMeOH™ process; Methanex Corporation, a global production and marketing firm for chemical-grade methanol products; Siemens Westinghouse, with power generation experience in advanced turbine systems; the Dow Chemical Company; and Dow Corning Corporation. Dynegy will use its gasification technology, now being demonstrated at the Wabash River integrated gasification combined-cycle plant in Terre Haute, Indiana. If the concept is feasible, the engineering design package will be for a plant at the Wabash facility.

Texaco Natural Gas, Inc. of Houston, Texas, will combine its gasification technology with the Rentech Inc. F-T technology to produce high-quality transportation fuels and electricity from coal and petroleum coke. Team members are Brown & Root Services, a division of Kellogg Brown & Root, Inc.; GE Power Systems; Praxair, Inc.; and Texaco Development Corporation. If the technology-integration concept is feasible, the engineering design package will be for a plant at one of several sites.

These three EECP partnerships will facilitate the development and commercial deployment of coproduction technologies to (1) enable industry to meet stringent emissions standards, (2) provide the capability to utilize more of our fossil energy resources for fuel production, and (3) strengthen our economy by establishing a new industry that uses our domestic fossil energy resources. Successful EECP projects will include fuel flexibility, product flexibility, superior environmental performance, and cost-competitive products. And by 2010, U.S. industry should be able to demonstrate that EECP facilities can cost effectively produce significant quantities of ultra-clean transportation fuels and chemicals from our domestic resources.

Beyond Coproduction: UTCF Initiative

Coproduction capability will provide a strong impetus for the entry of coal-derived transportation fuels into the U.S. market. However, larger plants in which fuel is the major product—using natural gas and petroleum-based feedstocks, in addition to coal—will be needed to meet our goal of establishing an industrial base that contributes significant quantities of ultra-clean transportation fuels to our Nation's fuel mix by 2020. FETC's Ultra-Clean Transportation Fuels (UCTF) initiative, scheduled to begin in fiscal year 2000, is the next step toward achieving this goal.

Industry participants suggested research and development priorities and government/industry partnering strategies to implement the UTCF initiative at a workshop in Dallas in the summer of 1999. The workshop helped identify current and potential barriers to achieving DOE's goals for the UTCF initiative and the technology approaches to overcoming them. Participants included senior managers and technology experts from the various segments of the fuels industry: companies that produce fuels and chemicals, industry trade and research organizations, and government research managers. (*Note: proceedings from the workshop are available by contacting Lisa Seich at FETC at 412/386-4803, or at seich@fetc.doe.gov.*)

Supplying the Nation's energy needs in an environmentally responsible manner is an enormous challenge. Our goal is to ensure that Americans will continue to enjoy the freedom they get from their cars, while leaving a legacy of clean air for our children. The technologies we develop will also expand and diversify the global resource base upon which ultra-clean fuels will be produced. The EECP and UCTF activities will help to supply America's drivers with clean fuels and clean air for many years to come.

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Vehicle Exhaust: NO_x, Particulates, and Sulfur

As a result of the Clean Air Act Amendments, the current NO_x standard for cars is 0.6 grams per mile (gpm), and the standard for trucks is 0.6 to 1.53 gpm, depending on the weight of the vehicle. The U.S. Environmental Protection Agency recently proposed Tier II emission standards for both cars and light-duty vehicles. These standards are currently being reviewed by industry. Projected to become effective in 2004, the Tier II standards, for the first time, would subject cars and light-duty trucks to the same NO_x emission levels at 0.07 gpm. The California Air Resources Board promulgated even more stringent NO_x emission standards at 0.02 gpm in December 1997.

Given these increasingly stringent standards, industry has a real challenge. In fact, as internal combustion engines become more efficient at burning fuel and reducing emissions of unburned hydrocarbons and particulate matter, the engines actually produce more NO_x—the opposite of what we want. In other words, if we reduce the particulate matter (a serious respiratory threat) using a more efficient engine, the additional air in the combustion chamber produces more NO_x, (a precursor to acid rain and smog). As the emission standards for NO_x and particulates continue to be lowered, more sophisticated engine and tailpipe controls—catalytic converters and filters—will need to be incorporated to reduce emissions to acceptable levels. In addition, the fact that sulfur in the fuel poisons the catalyst in the catalytic converter, preventing it from doing its job, means these new-age fuels will need to be ultra-low sulfur fuels as well.